FRANKFORD ARSENAL
Research and Development Group
Pitman-Dunn Laboratories
Philadelphia 37, Pa.

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Under 19

DEVELOPMENT OF THRUSTER, CARTRIDGE ACTUATED, XM14

Prepared by: C. Glaser
C. GLASER
Mechanical Engineer

Reviewed by: R. F. LeVino
R. F. LeVINO
Deputy Chief
Propellant Actuated Devices Div

Approved by: C. C. Fawcett
C. C. FAWCETT
Acting Chief
Research and Development Group
Pitman-Dunn Laboratories

For:

C. W. EIFLER
Colonel, Ordnance Corps
Commanding

ABSTRACT

A propellant actuated device, designated Thruster, Cartridge Actuated, XM14, was developed to act as a rammer for the 155 mm howitzer used in the T196 tank. This comprised a Receiver (Springfield, Model 1903-A3) and a modification of the qualified M19 Thruster (formerly T25). Being a more efficient and compact chambering device than the cumbersome and highly complex hydraulic mechanism formerly used, the thruster reduced projectile loading time, reduced repair time and cost, and conserved space within the tank.

Requirements for this thruster differed from those normally specified for propellant actuated devices in that the unit was required to fire repeatedly without maintenance. Design studies were initiated by conducting tests with a qualified thruster, the M19, modified to accept the firing mechanism of a standard rifle, which utilizes a standard cartridge (Cartridge, Rifle Grenade, Caliber .30, M3). On the basis of data accumulated in many subsequent development tests, the thruster was modified until it met or exceeded all performance requirements. A final engineering evaluation program confirmed the practicability of this device.

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INTRODUCTION

Frankford Arsenal received a request from the Ordnance Tank Automotive Center to design and develop a cartridge-actuated projectile rammer for the 155 mm howitzer used in the T196 tank. Unusual design problems existed because the rammer was required to operate for 25 firings without cleaning or maintenance, whereas the usual cartridge-actuated device has a one-shot function. Design problems arose also with respect to mounting and loading, since usable tank space was at a premium.

The initial concept of the rammer was based on the T25 thruster design. Modifications of this design evolved into the XM14 thruster which, basically, is a T25 thruster fitted to a standard rifle chamber and firing mechanism. Modifications on the T25 thruster design were dictated by the requirement of repeated firings without cleaning or maintenance. Development of the XM14 thruster was accomplished through a series of ballistic firings which were used for proving various design concepts.

The development and evaluation of the XM14 thruster are detailed in this report.

REQUIREMENTS

The XM14 thruster must provide the ramming force necessary to drive a 95-pound projectile a distance of 61 inches into the breech of the 155 mm howitzer, using a loading tray inclined 6° from the horizontal plane (at zero degrees tank elevation). The detailed performance requirements for the thruster are presented in Appendix A. A summary of the more pertinent requirements follows.

Firing cycle	25 rounds minimum, without maintenance
Stroke	11 inches maximum
Projectile chambering velocity	10 to 20 fps

Piston return	Manually repositioned
Recharging rate	3 to 4 rounds per minute
Operating temperature	-30° to 160° F
Life expectancy	500 to 1000 cycles
Locked-shut and no-load firings	Withstand firing without requiring repairs before refiring

DESIGN AND DEVELOPMENT

Design Studies

In February 1959, two design concepts for the projectile rammer were proposed by Frankford Arsenal. One system would use a bulky mechanical spring to provide the ramming action. Because of its complexity, this system received only brief consideration. The second system would use the existing hydraulic rammer, but would incorporate an oil-buffered device which would be recharged pneumatically by the weapon recoil after a projectile was fired. This system was rejected because it not only was complex, but it did not develop sufficient ramming pressure.

Subsequently a new chambering method using a cartridge-actuated thruster was proposed. For this special application it was thought that an existing, qualified thruster could be modified to meet performance requirements. After a survey of available thrusters, the T25 thruster was selected.

Development Testing

Development testing began with a T25 thruster which had been modified to accept a standard rifle chamber and firing mechanism. Although it was know that the unit was a single-shot device in which seals had to be replaced and the unit thoroughly cleaned after each firing, it was felt that the modified thruster, designated XM14 (Figure 1), would provide enough data in test firings to give a firm basis for design of the final unit. The thruster was mounted in the test rig shown in Figures 2 and 3. Test instrumentation is shown in Figure 4. A 95-pound mass, representing the projectile, was propelled vertically in the test rig by firing a .30 caliber M3 rifle grenade cartridge (Figure 5) in a standard 1903-A3 bolt-action rifle receiver fitted to the thruster. Table I list results recorded in six test firings.

Table I. INITIAL TEST DATA

Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.01360	7.4
2	0.01021	9.8
3	0.00861	11.6
4	(No reading)	-
5	(No reading)	-
6	0.00968	10.3

Although these results showed the feasibility of the approach, they indicated that a device with more thrust was required.

To improve the performance of the XM14, two principal changes were made. First, all major parts were fabricated from stainless steel so that the unit could be fired repeatedly without cleaning. Second, the piston area was increased almost 100 percent. As detailed in Table II, 25 rounds were fired in the test rig used previously. In these tests, the base line was adjusted to measure velocity over a distance of 0.10 foot.

Figure 1. XM14 Thruster

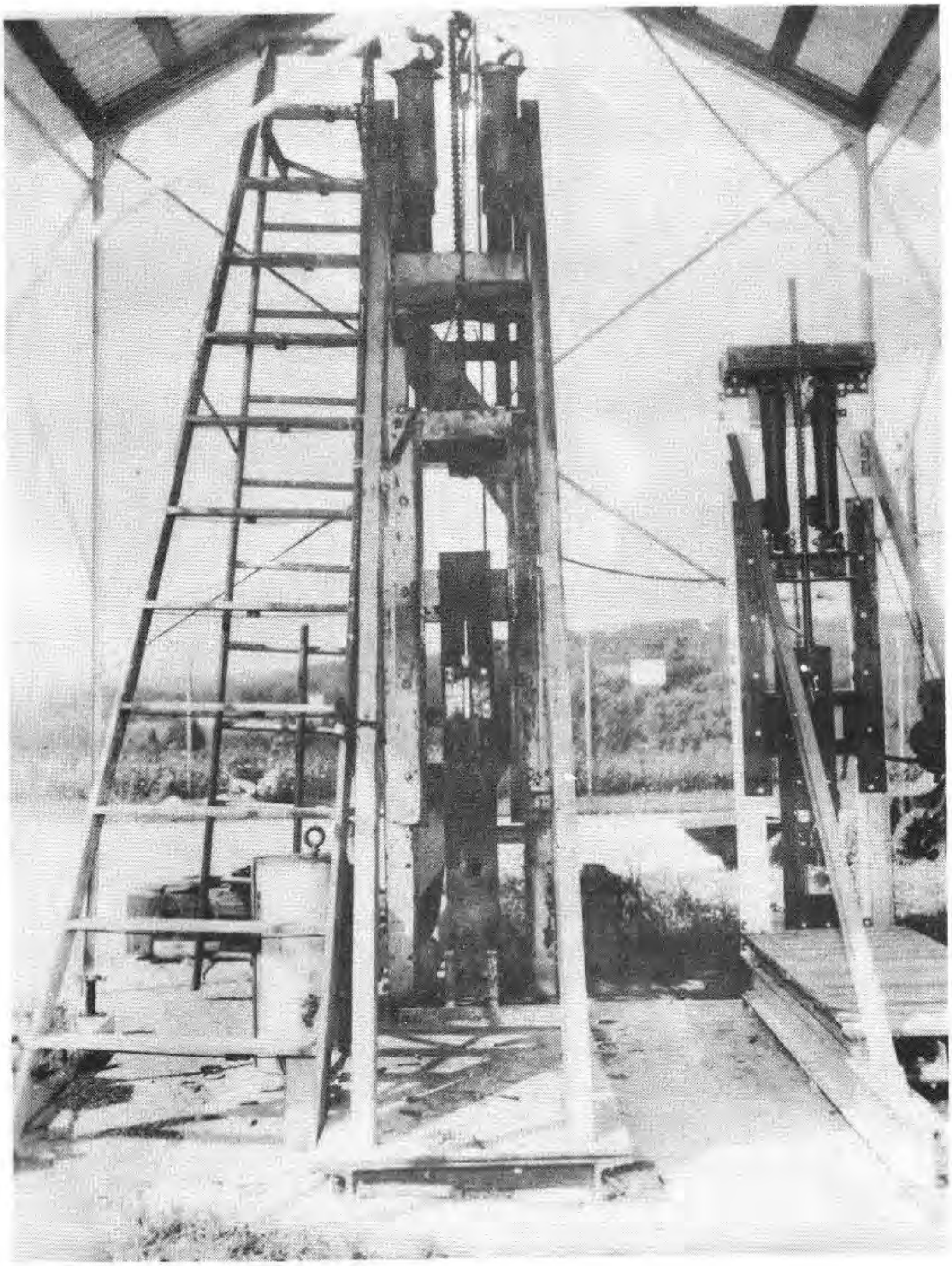

Figure 2. Test Stand

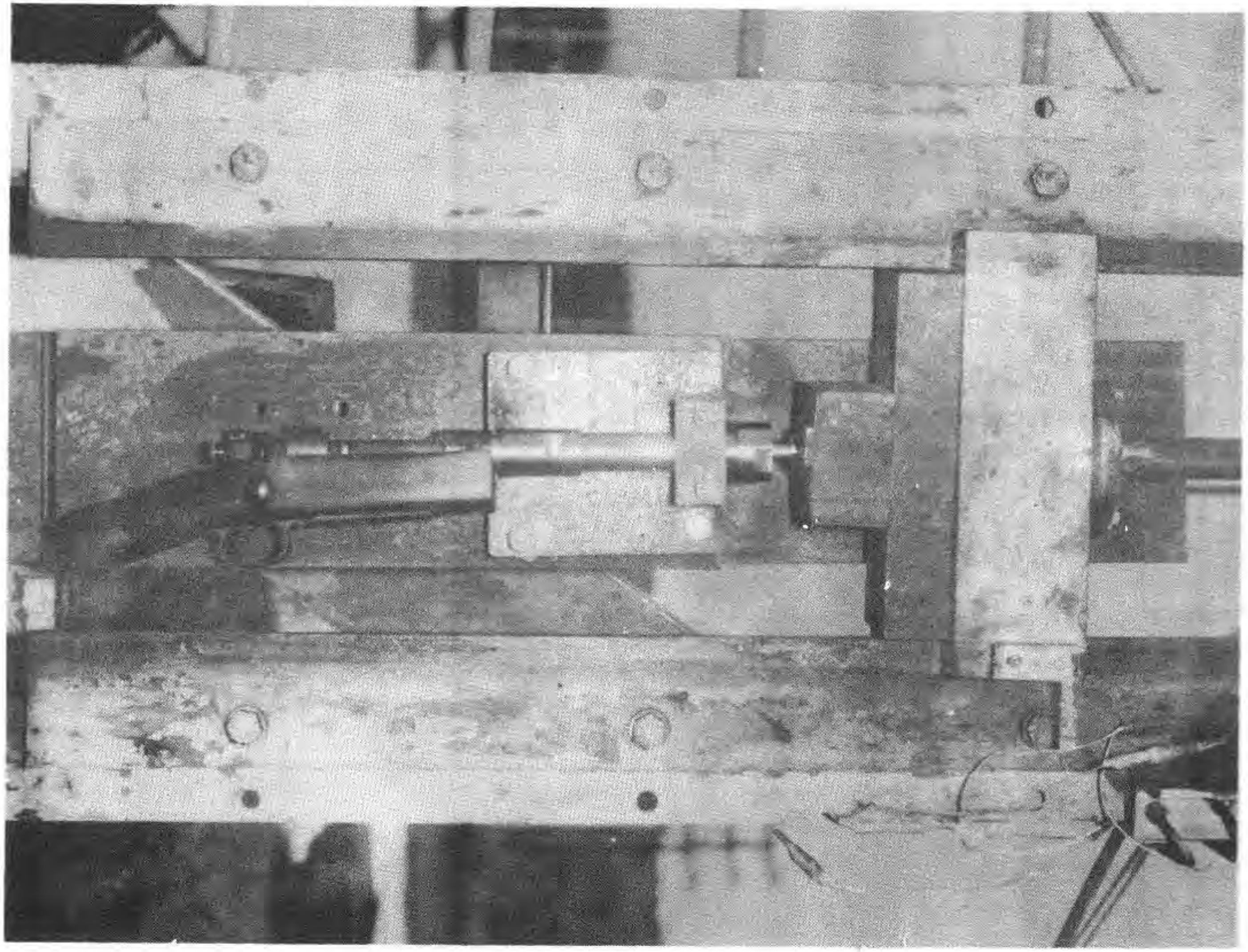

Figure 3. Close-up of Test Fixture with Thruster in place

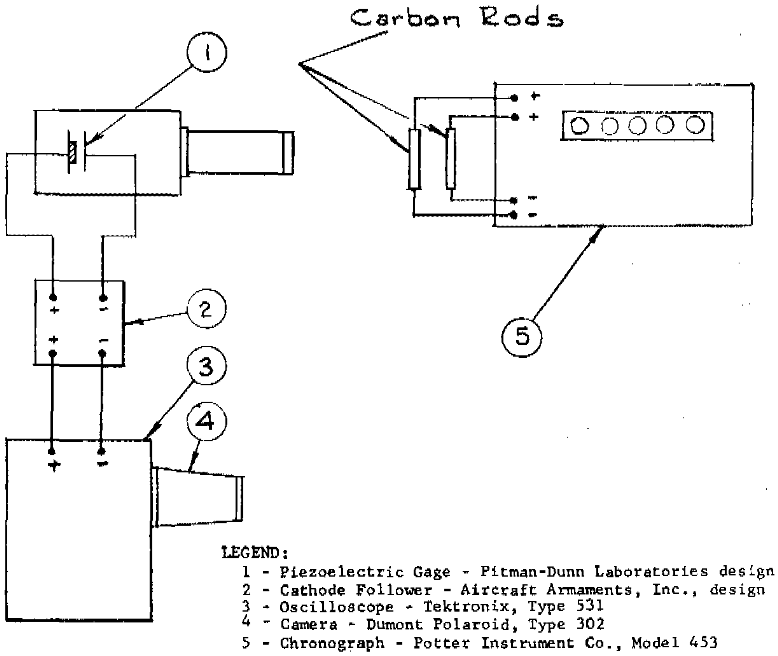

Figure 4. Test Instrumentation Setup

Table II. Test Data Obtained Following Hardware Modification

Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.00638	15.7	14	0.00551	18.2
2	0.00632	15.8	15	0.00581	17.2
3	0.00620	16.1	16	*	-
4	0.00554	18.1	17	*	-
5	0.00594	16.8	18	0.00604	16.6
6	0.00623	16.1	19	0.00638	15.7
7	0.00580	17.3	20	*	-
8	0.00567	17.6	21	*	-
9	*	-	22	*	-
10	*	-	23	0.00614	16.3
11	*	-	24	0.00576	17.4
12	0.00581	17.2	25	0.00553	18.1
13	*	-			

Extremes: 15.7 - 18.2 fps
Average velocity: 16.9 fps

*No chronograph readings taken

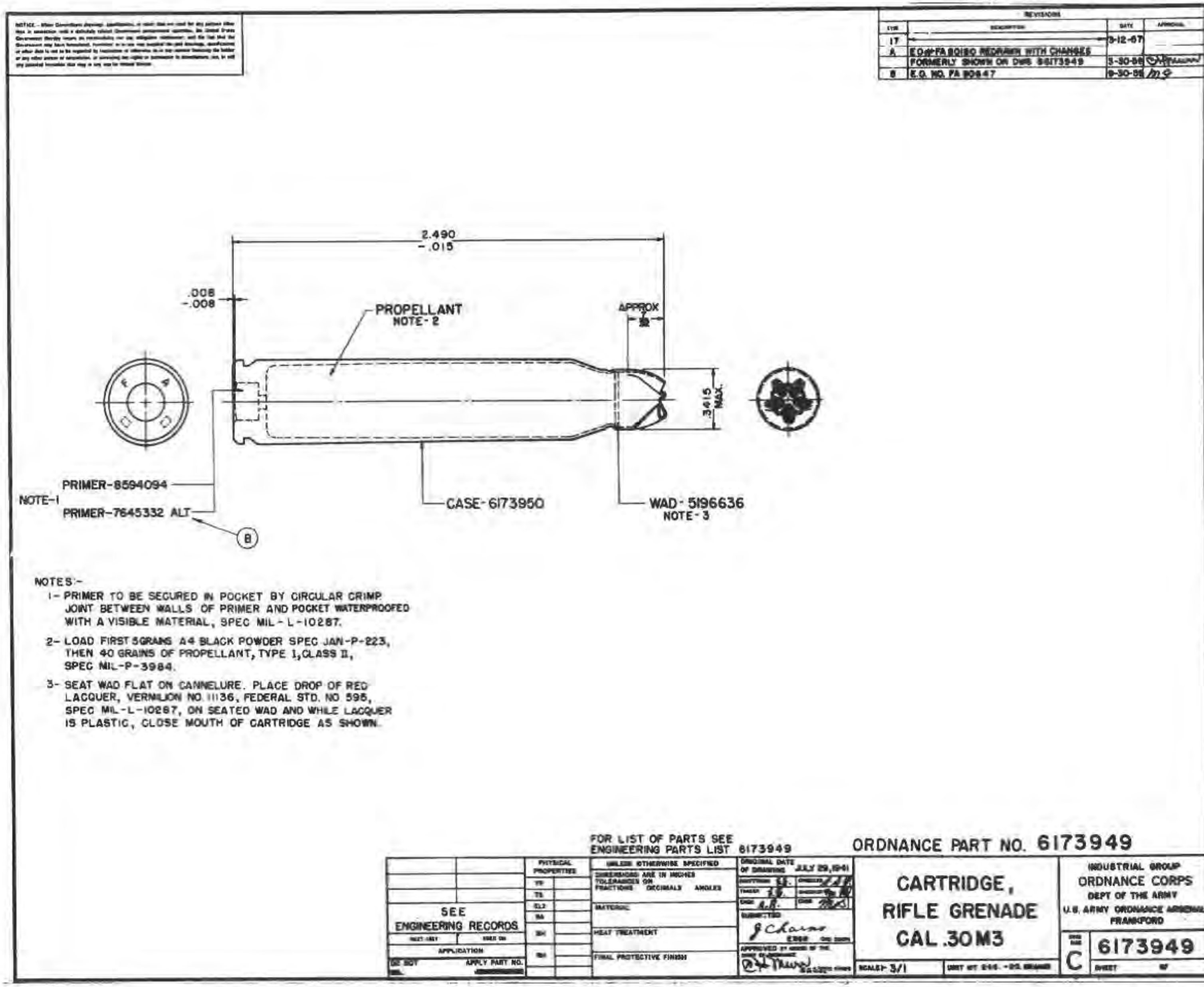

Figure 5. Cartridge, Rifle Grenade, Caliber .30, M3

These data show that the average velocity was well within the required limits and that the performance of the unit did not deteriorate over the required 25 rounds. However, after each shot it was very difficult to return the piston to its firing position; in fact, it could be returned only by hammering on it repeatedly. To relieve this condition, the piston was modified in order to allow the gas to flow between the piston and the body of the thruster. This, it was believed, would greatly reduce the velocity of the piston as it neared the end of its travel. When this modified unit was fired under a no-load condition, the piston fractured at an undercut area (area A in Figure 6).

The undercut in the piston was eliminated and the piston was made as shown in Figure 7. However, the body of the thruster was undercut. This thruster was fired under the no-load condition and the piston did not break. No measurable deformation of the piston resulted and no dangerous gas leaks were observed.

It was then felt that the time-pressure curves of this unit should be established under no-load, locked-shut, and normal firing conditions. Six firings were made with the results listed in Table III. The time-pressure curves obtained on the oscilloscope are shown in Figure 8, 9, and 10.

It should be noted that for these firings the base line was 0.2 foot. Due to the increased initial volume of the thruster, which was modified to facilitate the time-pressure curve instrumentation, slightly lower than desired velocities were experienced.

Following the no-load test, the length of the piston was measured and it was found that it had elongated from 4.550 to 4.606 inches, or approximately 1/16 inch. The piston was then checked with fluorescent dye to detect any fractures, but none were found. A high-speed movie was made of the no-load firing, but the results were of too short a duration to be interpreted.

Table III. Normal, Locked-Shut, and No-Load Firing Data

Type of Firing	Round No.	Chronograph Reading (sec)	Velocity (fps)	Maximum Pressure (psi)
Normal	1	0.0157	12.7	14,700
Normal	2	0.0155	12.9	13,900
Normal	3	0.0150	13.3	15,500
Locked-Shut	4	-	-	15,800
Locked-Shut	5	-	-	15,500
No-Load	6	-	-	12,200

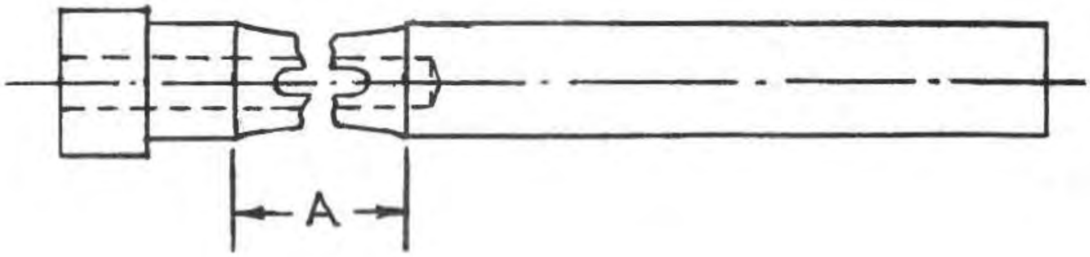

Figure 6. Piston Failure Area

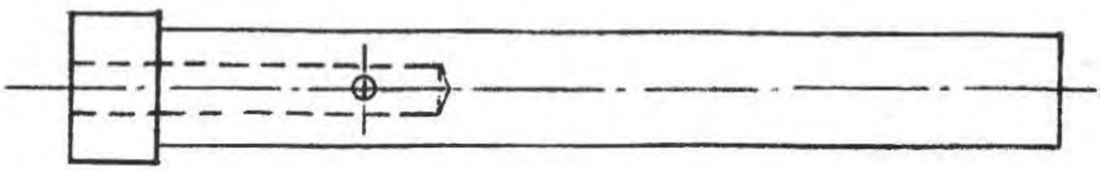

Figure 7. Final Piston Design

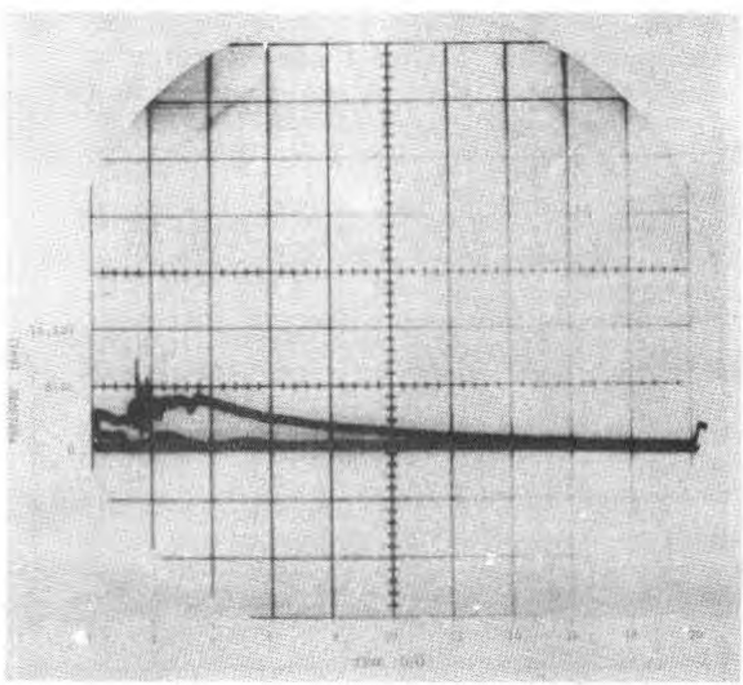

Figure 8. Time-Pressure Curve, No-load Firing

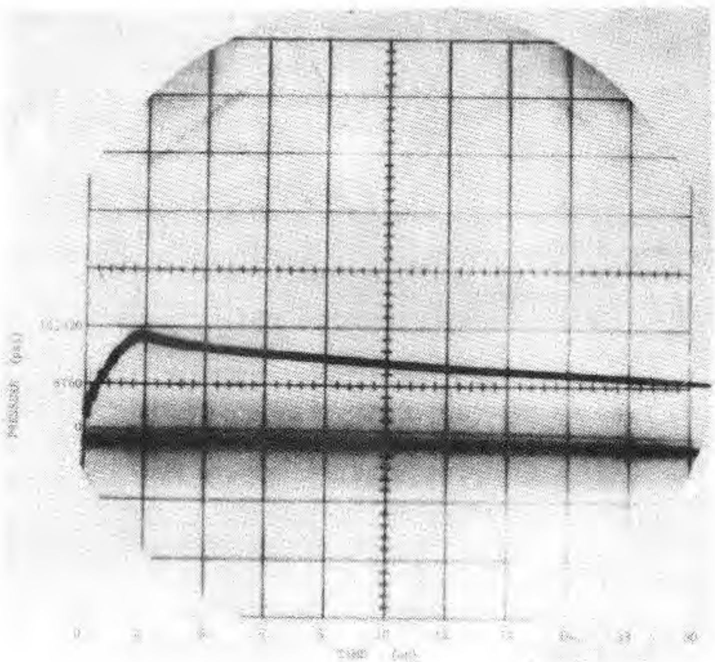

Figure 9. Time-Pressure Curve, Locked-shut Firing

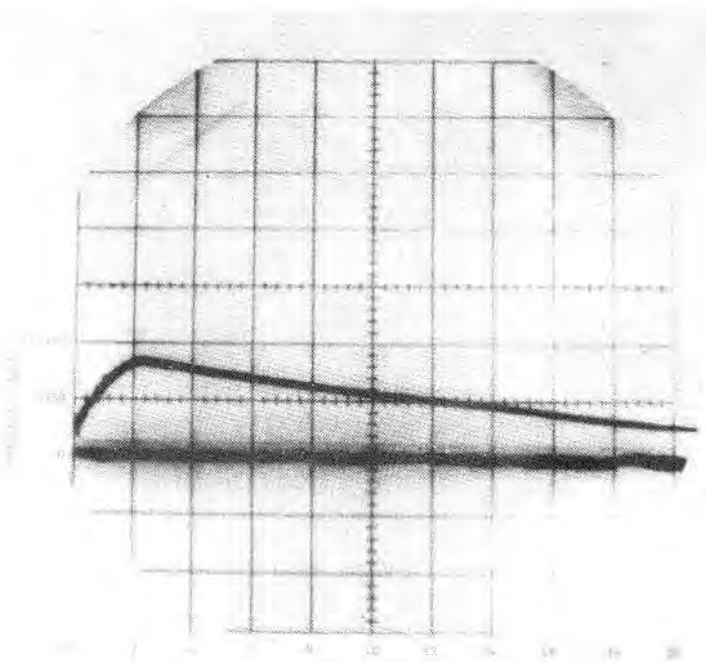

Figure 10. Time-Pressure Curve, Normal Firing

Attention was next given to the problem of easing the return of the piston after a firing. Sticking of the piston was apparently caused by a buildup of the propellant residue inside the thruster. The first solution attempted was enlargement of the hole in the body through which the piston passed. Five shots were fired after this change, but the piston could not be returned by hand pressure after the third shot. It was felt that if a steel piston ring, doubling as a scraper, were placed on the head of the piston an easier return might result. However, after the eighth shot, the piston could no longer be returned by hand. To correct this, the steel piston ring was replaced with one of Teflon, and twelve shots were fired. In this condition the piston was returned easily each time. Performance was not recorded.

During this period, work had also progressed on the redesign and fabrication of the mounting tray and hardware supplied by the Detroit Arsenal. The tray, together with the mounting hardware, was completely rebuilt with almost all new parts. This unit with the thruster mounted may be seen in Figures11 and 12. During this period, a new thruster body was fabricated of stainless steel to replace the one modified for pressure measurement.

On 10 June 1959, the XM14 thruster and mounting hardware were taken to the Detroit Arsenal to demonstrate the compatibility of their design with the T196 tank. This was accomplished by simulating actual loading conditions in the tank. Twenty-six ramming operations were conducted. Though these firings were not instrumented, it was noted that the chambering velocities did not appear to be uniform. Inspection of the Teflon ring after the tests showed that it had deteriorated, and this was thought to have caused the nonuniformity in ramming velocities.

The unit was returned to Frankford Arsenal and modified by removing 0.002 inch from the outer diameter of the previously used steel piston ring. The ring was replaced on the piston, and 20 shots were fired. The results of these shots are listed in Table IV. The velocites were low, and this was attributed to the large clearance between the body and the piston. The piston could be returned by hand pressure until the twelfth shot.

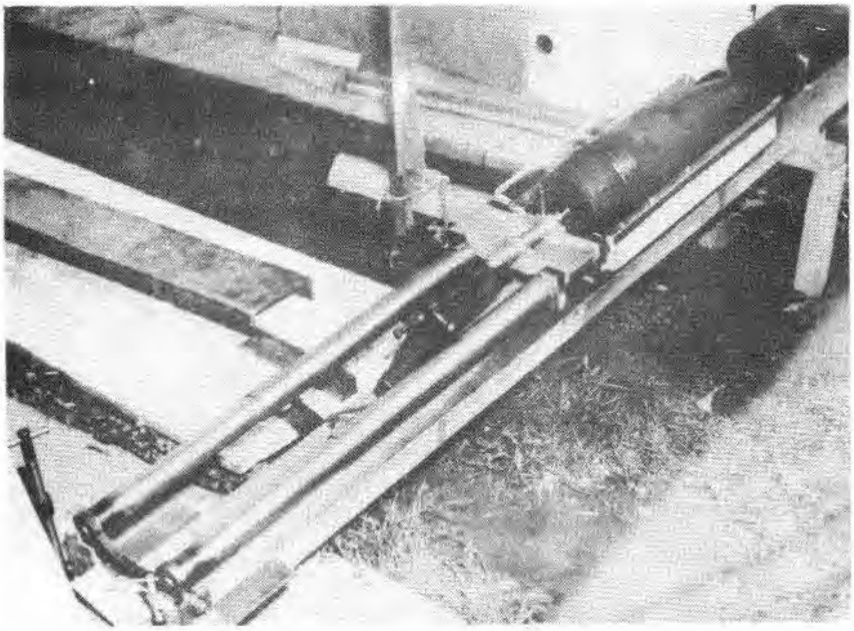

Figure 11. XM14 Thruster and Mounting Tray

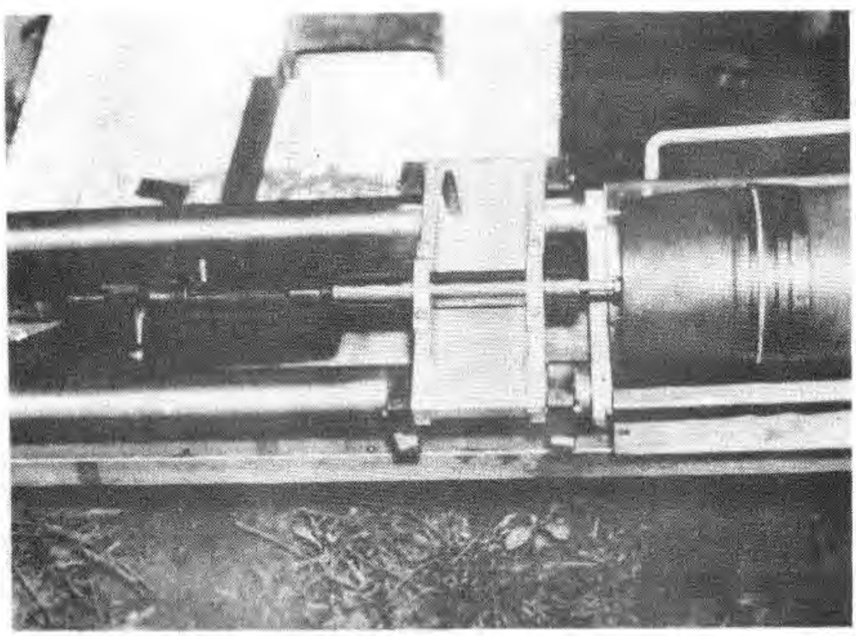

Figure 12. Close-up of Mounted XM14 Thruster and Projectile

Table IV. Test Data Obtained Following Piston Ring Modification

Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.017	11.8	11	0.017	11.8
2	0.018	11.1	12	0.016	12.5
3	-	-	13	0.017	11.8
4	0.017	11.8	14	0.017	11.8
5	0.017	11.8	15	0.017	11.8
6	0.017	11.8	16	0.016	12.5
7	0.018	11.1	17	0.017	11.8
8	0.016	12.5	18	0.019	11.5
9	0.016	12.5	19	0.017	11.8
10	0.016	12.5	20	0.016	12.5

From these tests it was concluded that the seal between the piston and body would have to be redesigned to seal effectively without binding the piston. In the first attempt, a metal ring was placed in an undercut at the end of the body and held in place by an end cap on the body. It was hoped that the small area of contact between the ring and the piston, as opposed to the large contact area between the body and piston in the original seal, would facilitate piston return by hand pressure. Ten shots were fired with the result listed in Table V. Not only was velocity low, but return of the piston was difficult.

Table V. Test Data Obtained Following Seal Modification

Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.015	13.3	6	0.014	14.3
2	0.016	12.5	7	0.014	14.3
3	0.015	13.3	8	0.014	14.3
4	0.013	15.5	9	0.013	15.5
5	0.014	14.3	10	0.014	14.3

Following these firings, a rubber O-ring was placed between the end cap and the body, and five shots were fired to check the effect of this change on velocities. This test was successful in that leakage near the end of the stroke was minimized; velocities increased accordingly (see Table VI). After the fifth shot the piston could still be returned by hand, but with difficulty.

Table VI. Test Data Obtained Following O-Ring Addition

Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.0120	16.7
2	0.0124	16.1
3	0.0126	15.9
4	0.0122	16.4
5	0.0124	16.1

In firings with the new end cap, a rubber O-ring, and a metal piston ring, velocities were satisfactory but by the fifth shot, the piston could not be returned by hand. The results are given in Table VII.

Table VII. Test Data Obtained After Addition of End Cap and Rings

Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.01130	17.6
2	0.01200	16.7
3	0.01120	17.8
4	0.01125	17.7
5	0.01127	17.7

In an effort to determine the cause of the difficulties in piston return, the ring on the head of the piston was removed and the unit was fired five times. Removal of this ring did not affect velocity since this unit operates with the same pressure on both sides of the piston head. However, it was felt that removal of this ring would eliminate one possible cause of piston binding. The condition was not corrected, leading to the conclusion that binding was caused by the exit sealing ring. As can be seen from the test results listed in Table VIII, the velocity was almost unaffected by the removal of the ring from the piston head. Actually, velocity increased slightly due to lower friction.

Table VIII. Test Data Obtained with Piston Head Ring Removed

Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.01143	17.5
2	0.01130	17.7
3	0.01110	18.0
4	0.01082	18.5
5	0.01070	18.7

It was now obvious that the sticking of the piston was caused by either the end cap or the exit sealing ring. As a remedial measure the hole in the end cap through which the piston passed was enlarged. Five shots were fired without recording velocity. After the third the piston stuck. The hole was further enlarged and ten more shots fired, again without recording velocities. The piston bound after the eighth shot, and the unit was disassembled for a careful inspection. It was found that the exit sealing ring had been peened over the shoulder on the end cap, thereby binding the piston. After careful consideration of the problem, it was decided to install a Teflon seal between the body and the metal seal. At the same time, the hole in the metal seal through which the piston passed was enlarged still more to allow the piston to return when the gas pressure was relieved but not so much that the Teflon ring would not seal under pressure. In other words, the Teflon would, under gas pressure, expand into the gap between the piston and the metal ring but would relax when the gas pressure was relieved. Modifications were made by assuming dimensions for the Teflon ring and the hole in the metal seal. The unit was reassembled and fired. Inspection of the data in Table IX shows that the velocities are low, indicating excessive clearance between the rings and the piston. However, the tests indicated design progress since after 26 shots the piston could still be returned easily by hand pressure. It should be noted that only enough chronograph readings were taken to make certain that velocities were not changing radically; i.e. the seals were not deteriorating.

Table IX. Test Data Obtained Following Seal and Hole Modification

Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.0151	13.2	14	0.0160	12.5
2	0.0150	13.3	15	0.0160	12.5
3	0.0162	12.4	16	*	-
4	0.0153	13.1	17	0.0158	12.8
5	0.0160	12.5	18	0.0156	12.8
6	*	-	19	*	-
7	*	-	20	*	-
8	0.0156	12.8	21	*	-
9	0.0160	12.5	22	*	-
10	*	-	23	0.0160	12.5
11	*	-	24	0.0158	12.8
12	*	-	25	*	-
13	0.0160	12.5	26	0.0154	13.0

*No chronograph reading taken

Following this test, there remained only the problem of accurately dimensioning the Teflon and metal seal to give the pressure seal required. New rings were made and the unit was reassembled with both seals and the rubber O-ring. At the beginning of this test, two rounds misfired and in one round the primer was pierced. The bolt of the rifle firing mechanism was inspected carefully, was found to be defective, and was, therefore, replaced. No difficulties were experienced during the remainder of the testing program.

Following the replacement of the bolt, ten rounds were fired. In all rounds the results were very satisfactory and the piston returned easily. The results are listed in Table X.

Table X. Test Data Obtained Following Bolt Replacement

Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.0128	15.7	6	0.0121	16.5
2	0.0125	16.0	7	0.0117	17.1
3	0.0124	16.1	8	0.0114	17.5
4	0.0121	16.5	9	0.0115	17.3
5	0.0117	17.1	10	0.0114	17.5

Following the tests summarized in Table X, which were conducted to meet the work statement requirements that the chambering device should, during the development phase, operate satisfactorily at ambient temperatures, six rounds were fired with XM14 thrusters condtioned at -30°F, and six rounds were fired with the units conditioned at 160°F. For the -30°F tests, the assembly and the cartridge, but not the firing mechanism, were exposed to the conditioning temperature for four hours. After each firing the unit was conditioned at -30°F for one hour prior to the next firing. (Initially, the firing mechanism also was subjected to a temperature of -30°F, but upon its removal from the conditioning chamber, so much ice formed on and around the firing pin that the pin could not be moved. Since the ice formation resulted from the sudden and severe change in temperature and humidity conditions, no difficulties would be encountered if the unit was conditioned and fired in an atmosphere of -30°F.) The results of these test firings are listed in Table XI.

Table XI. Test Data Obtained with -30°F Conditioning

Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.0130	15.4
2	0.01218	16.4
3	0.01207	16.5
4	0.01203	16.5
5	0.01160	17.2
6	0.01184	16.8

In the 160°F tests the cartridge and the thruster were exposed to the required temperature for three hours before the first firing. They were not refired until they had been exposed to 160°F for one hour. The results of these tests may be seen in Table XII.

Table XII. Test Data Obtained with 160°F Conditioning

Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.0109	18.3
2	0.0111	18.0
3	0.0111	18.0
4	0.0112	17.9
5	0.0109	18.3
6	0.0114	17.5

The results shown in Tables X, XI, and XII represent the testing required as proof of design. The figures represent the velocity of a 95-pound mass, a simulated 155 mm shell, propelled vertically. Only after they are adjusted (refer to Appendix B) to take into account the 6° incline and the friction of the shell in the tray, do these figures represent chambering velocities.

Table XIII shows the extreme and average velocities given in Tables X, XI, and XII converted to chambering velocities.

Table XIII. Summary of Chambering Velocities

	Table X (70°F)			Table XII (160°F)			Table XI (-30°F)		
	High	Low	Avg.	High	Low	Avg.	High	Low	Avg.
Measured Velocity	17.5	15.7	16.7	18.3	17.5	18.0	17.2	15.4	16.5
Chambering Velocity	15.9	14.1	15.1	16.7	15.9	16.4	15.6	13.8	14.9

The average velocity over the entire temperature range is the average of the 160°F and -30°F averages, or $(16.4 + 14.9) \div 2 \approx 15.65$ fps.

This value is well within the 10 to 20 fps velocity requirement. The total deviation during the entire development testing program was 13.8 to 16.7, or 2.9 fps. After these test results were obtained, the engineering evaluation program was initiated.

Layout and Operation

The XM14 thruster, as shown in Figures 13 and 14, is composed of three main components: the receiver, the rifle grenade cartridge, and a modified version of the T25 thruster. The envelope dimensions for the XM14 thruster are shown in Figure 15.

A conventional bolt-action receiver is used to contain and fire the rifle grenade cartridge. Loading and firing procedures are identical to those used with a conventional rifle. When the rifle grenade cartridge is fired, it generates a high-pressure gas which exerts pressure against the piston, causing it to move forward. The gas escapes through ports in the piston (refer to Figure 16), fills the void ahead of the piston, and thus tends to slow down piston operation. As the gas travels toward the end of the body, it passes through annular rings (buffering chambers) and in doing so further slows piston operation. The buffered piston stroke of approximately 3.25 inches imparts to the 95-pound projectile sufficient velocity to travel a distance of 61 inches from the rammer tray (details shown in Figures 17 through 20) to seat firmly into the breech of the 155 mm howitzer. With a tray elevation of 6° at a tank elevation of 0°, the projectile ramming velocity is 15.7 feet per second. After the projectile is chambered, the piston is manually repositioned.

Incidental to and necessary for use with the XM14 Thruster, Frankford Arsenal designed a new rammer tray which facilitated ease of loading. When not in use, this new rammer tray (shown in Figures 17 through 20) can be folded to provide additional space for the tank crew or for temporary storage.

Figure 13. XM14 Thruster and Rifle Grenade Cartridge

Figure 14. XM14 Thruster, Exploded View

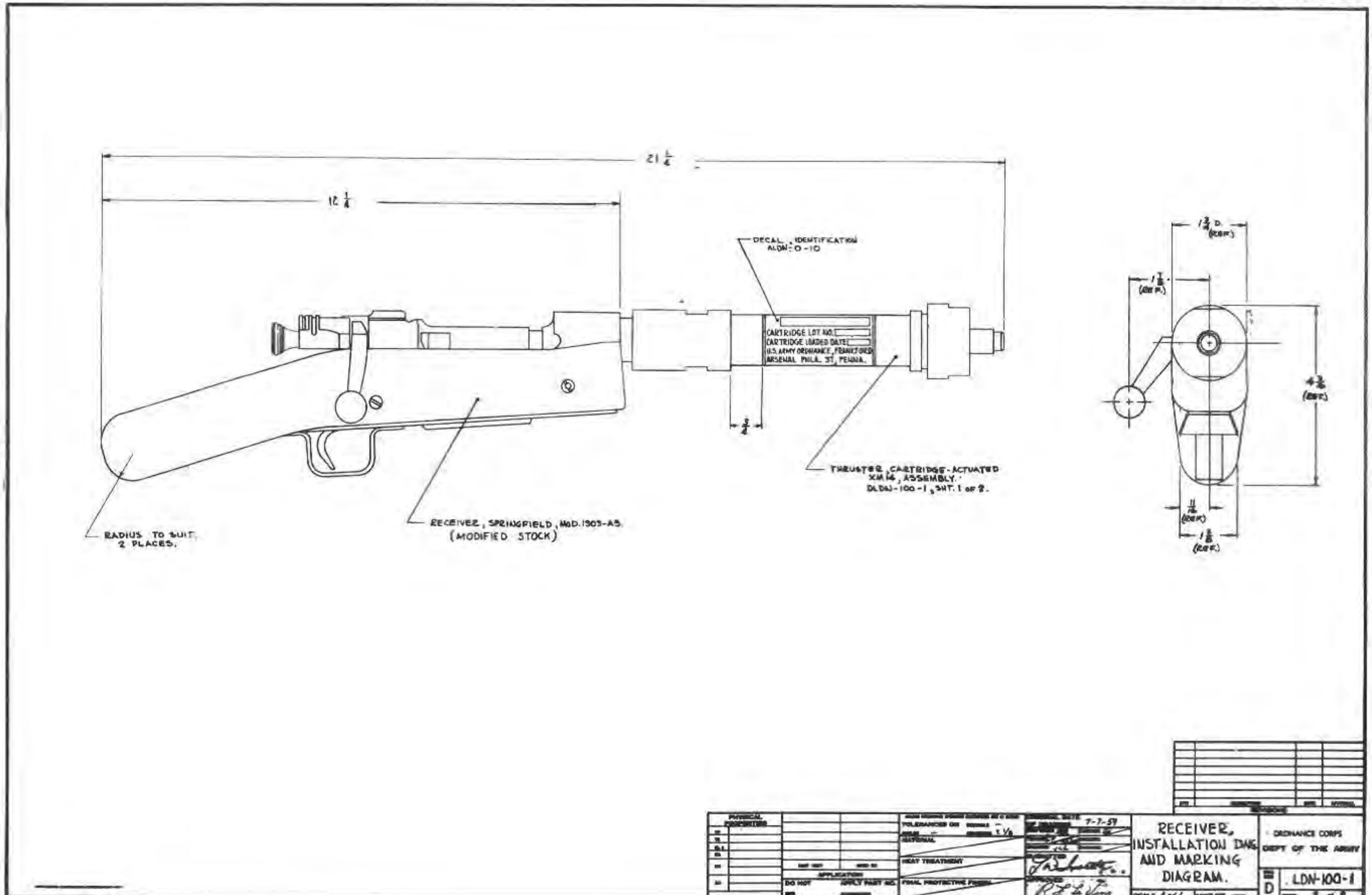

Figure 15. Installation drawing and marking diagram, Receiver

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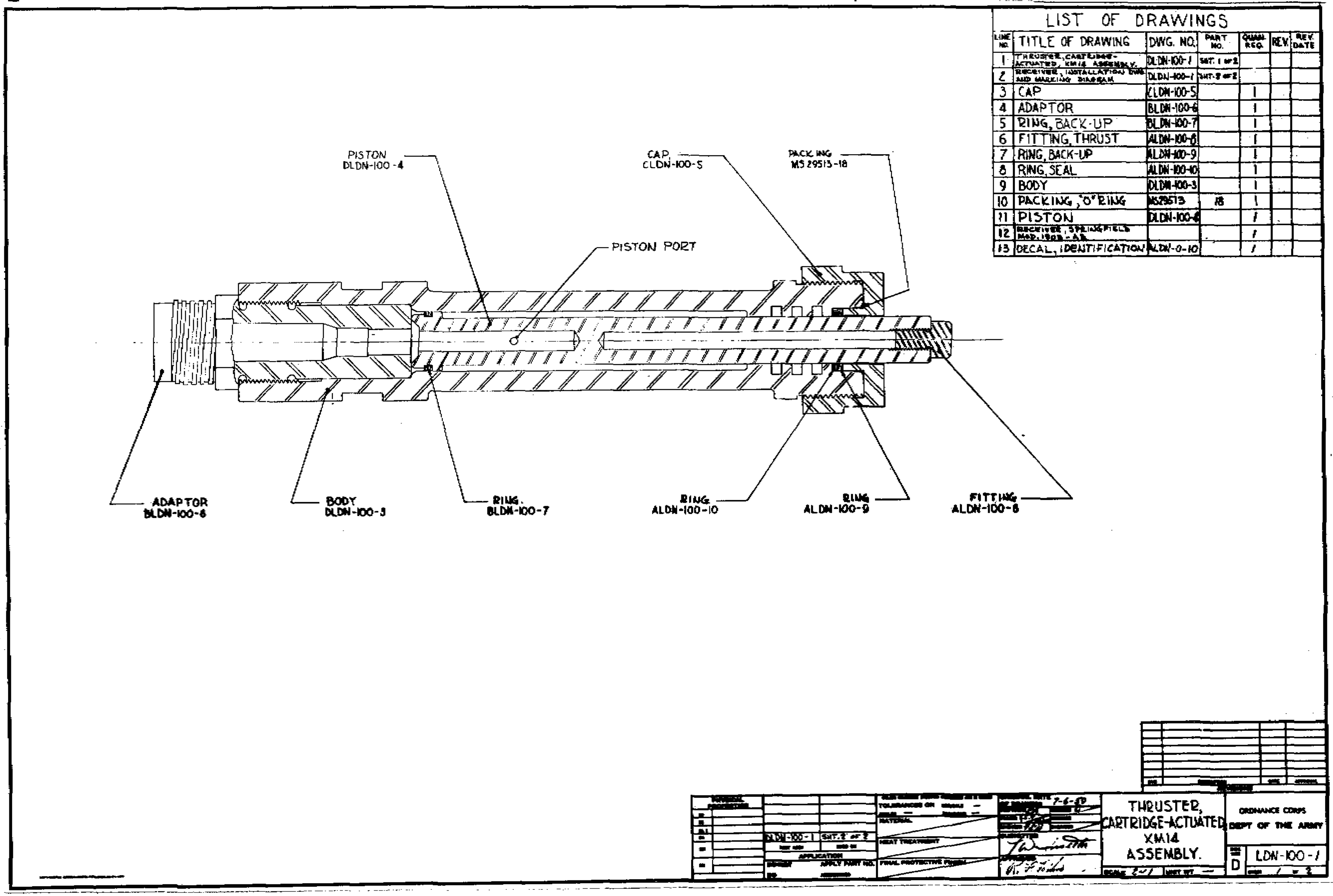


Figure 16. Assembly, Thruster, Cartridge Actuated, XM14

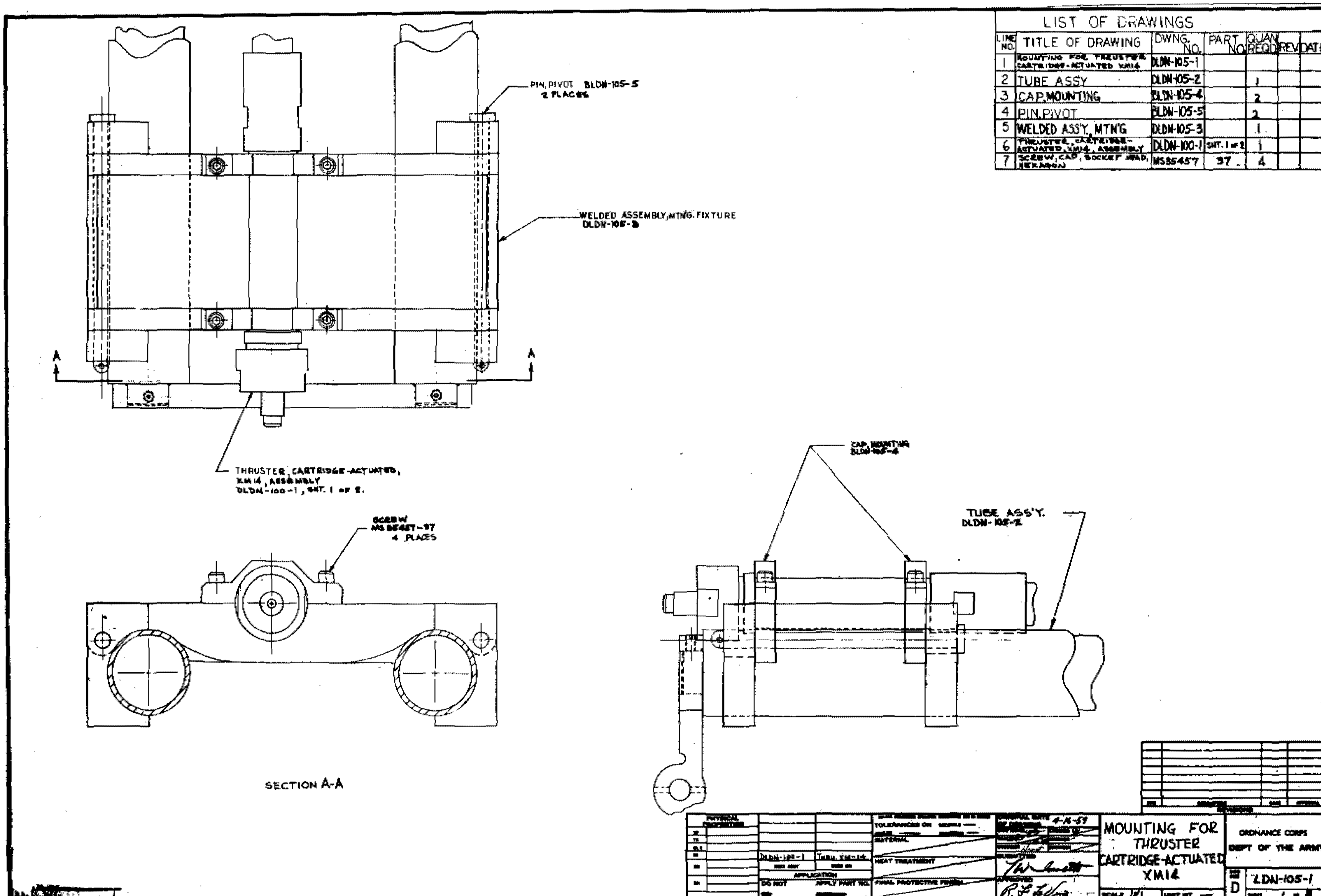


Figure 17. Mounting for Thruster, Cartridge Actuated, XM14

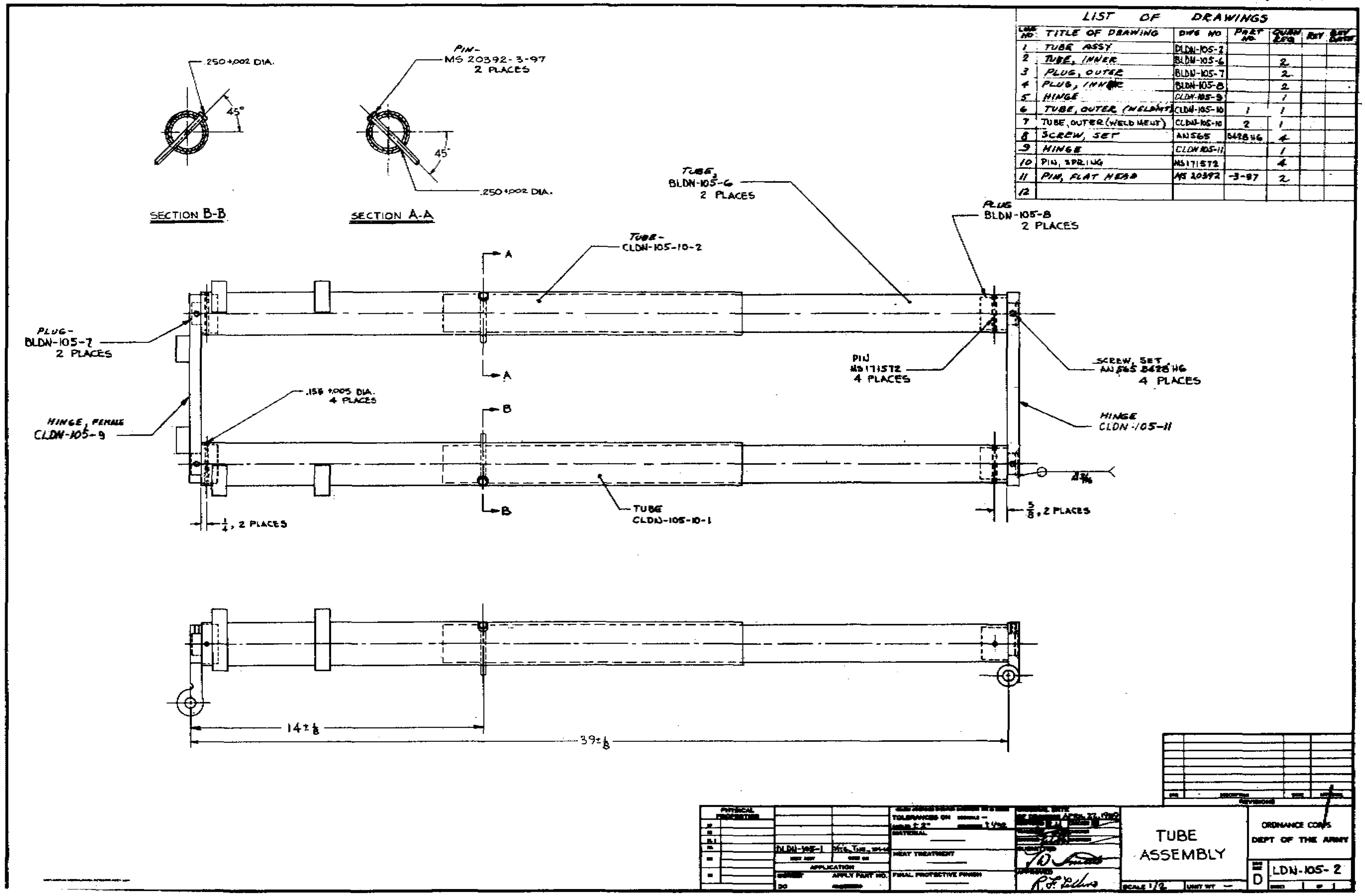


Figure 18. Tube assembly

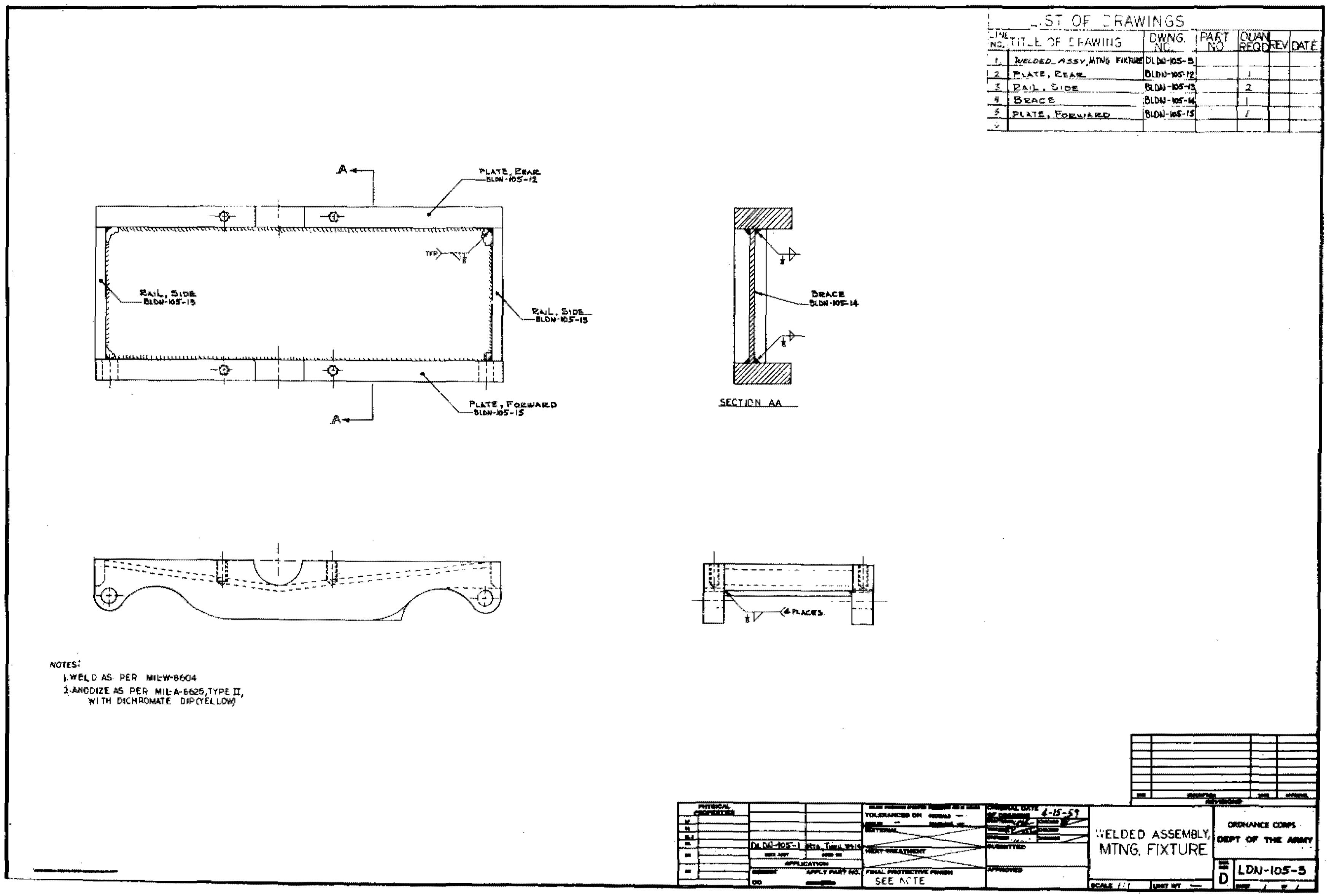


Figure 19. Welded assembly, Mounting Fixture

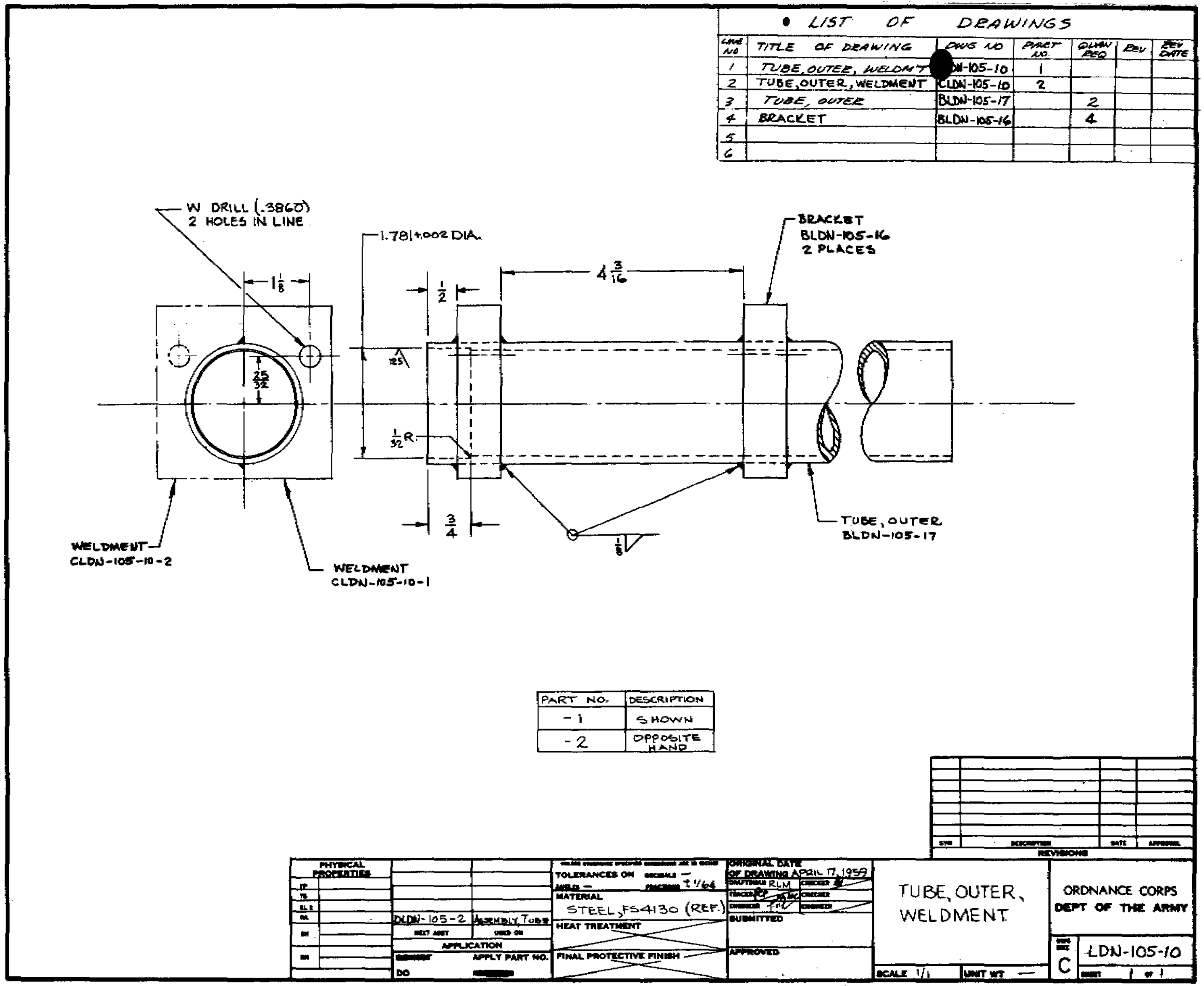


Figure 20. Weldment, Outer Tube

ENGINEERING EVALUATION

Final Ballistic Testing

Final ballistic test firings were conducted with five units. Because the Detroit Arsenal desired two of these units as soon as possible, the first two units fabricated (No. 1 and No. 3) were each fired five times at 70°F, were reconditioned, and shipped to Detroit Arsenal for their retention and evaluation. The results of the firings are presented in Table XIV.

Table XIV. Engineering Evaluation of Units Nos. 1 and 3

	Unit No. 1		Unit No. 2	
Round No.	Chronograph Reading (sec)	Velocity (fsp)	Chronograph Reading (sec)	Velocity (fps)
1	0.0124	16.2	0.0122	16.5
2	0.0119	16.8	0.0119	16.8
3	0.0121	16.5	0.0115	17.3
4	0.0119	16.8	0.0114	17.4
5	0.0120	16.6	0.0114	17.4

Following this test, two of the three remaining units were conditioned at -30°F, and a total of twenty roundswas fired. The results of these tests are reported in Table XV.

Table XV. Test Data Obtained with Units Conditioned at -30°F

Unit No. 2			Unit No. 4		
Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.01206	16.5	11	0.01189	16.8
2	0.01223	16.3	12	0.01149	17.4
3	0.01190	16.8	13	0.01230	16.7
4	0.01170	17.0	14	0.01191	16.8
5	0.01156	17.8	15	0.01321	15.2
6	0.01130	17.6	16	0.01242	16.1
7	0.01219	16.4	17	0.01238	16.2
8	0.01250	16.0	18	0.01304	15.3
9	0.01246	16.0	19	0.01193	16.7
10	0.01267	15.8	20	0.01131	17.7

Units No. 2 and No. 4, were now considered ready for shipment, but first each was fired five times at 70°F with the results shown in Table XVI.

Table XVI. Test Data Obtained with Final Units at 70°F

Unit No. 2			Unit No. 4	
Round No.	Chronograph Reading (sec)	Velocity (fps)	Chronograph Reading (sec)	Velocity (fps)
1	0.01140	17.5	0.01132	17.7
2	0.01145	17.5	0.01120	17.8
3	0.01112	18.0	0.01120	17.8
4	0.01132	17.7	0.01070	18.6
5	0.01119	17.8	0.01112	18.0

The remaining unit (No. 5),was fired 20 times with both the thruster and the cartridge conditioned at 160°F. These tests are reported in Table XVII.

Table XVII. Test Data Obtained with Unit No. 5 Conditioned at 160°F

Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.01140	17.6	11	0.01120	17.8
2	0.01086	18.3	12	0.01094	18.3
3	0.01151	17.4	13	0.01078	18.5
4	0.01131	17.7	14	0.01082	18.5
5	0.01133	17.7	15	0.01090	18.3
6	0.01109	18.3	16	0.01098	18.0
7	0.01133	17.7	17	0.01126	17.8
8	0.01122	17.8	18	0.01101	18.3
9	0.01109	18.0	19	0.01121	17.9
10	0.01101	18.2	20	0.01166	17.2

Following these tests, the required 20 rounds were fired with unit No. 5 at 70°F. This test was then extended to 50 rounds without cleaning the unit, more than double the number required. During rounds 21 to 50, velocity was recorded on every fifth round only. These firings are listed in Table XVIII.

Table XVIII. Test Data Obtained with Unit No. 5 Conditioned at 70°F

Round No.	Chronograph Reading (sec)	Velocity (fps)	Round No.	Chronograph Reading (sec)	Velocity (fps)
1	0.01127	17.8	14	0.01192	16.8
2	0.01120	17.9	15	0.01220	16.4
3	0.01141	17.5	16	0.01200	16.7
4	0.01135	17.6	17	0.01181	17.0
5	0.01142	17.5	18	0.01144	17.5
6	0.01098	18.2	19	0.01171	17.1
7	0.01128	17.8	20	0.01098	18.2
8	0.01160	17.2	25	0.01094	18.3
9	0.01119	17.9	30	0.01140	17.6
10	0.01161	17.2	35	0.01099	17.2
11	0.01196	16.7	40	0.01115	17.0
12	0.01260	15.9	45	0.01200	16.7
13	0.01220	16.4	50	0.01134	17.6

The only test requirement remaining was the firing of ten locked-shut rounds and five no-load rounds, all with assemblies conditioned at 160°F. After ten locked-shut firings, the units were inspected. No damage was noted. In the five no-load firings, a separate piston was used for each shot and in each case the length of the piston was measured before and after firing. The measurements are shown in Table XIX. Figure 21 is a photograph of the pistons after firing.

Table XIX. Piston Elongation with No-load (Conditioning Temperature, 160°F)

Round No.	Length (in.) Before Firing	After Firing	Elongation (in.)
1	5.970	6.150	0.180
2	5.970	6.200	0.230
3	5.980	6.225	0.245
4	5.970	6.200	0.230
5	5.980	6.225	0.245

After the completion of these tests, two more shots were fired so that the porting of the gas could be photographed by a high-speed motion picture.camera. An initial puff of gas was observed, then as the port passed the Teflon seal in the front of the thruster, the final exhausting of gas took place.

Table XX shows the high, low, and average velocities recorded for all firing conditions during the engineering evaluation program. The table also shows the chambering velocities represented by the recorded velocities (refer to Appendix B).

Table XX. Summary of Velocity Values

	Velocity (fps) 70°F			160°F			-30°F		
	High	Low	Avg.	High	Low	Avg.	High	Low	Avg.
Measured Velocity	18.6	15.9	17.3	18.5	17.2	18.0	17.8	15.3	16.6
Chambering Velocity	17.0	14.3	15.7	16.9	15.6	16.4	16.2	13.7	15.0

The average velocity over the entire temperature range is the average of the 160°F and -30°F averages, or $(16.4 + 15) \div 2 = 15.7$ fps.

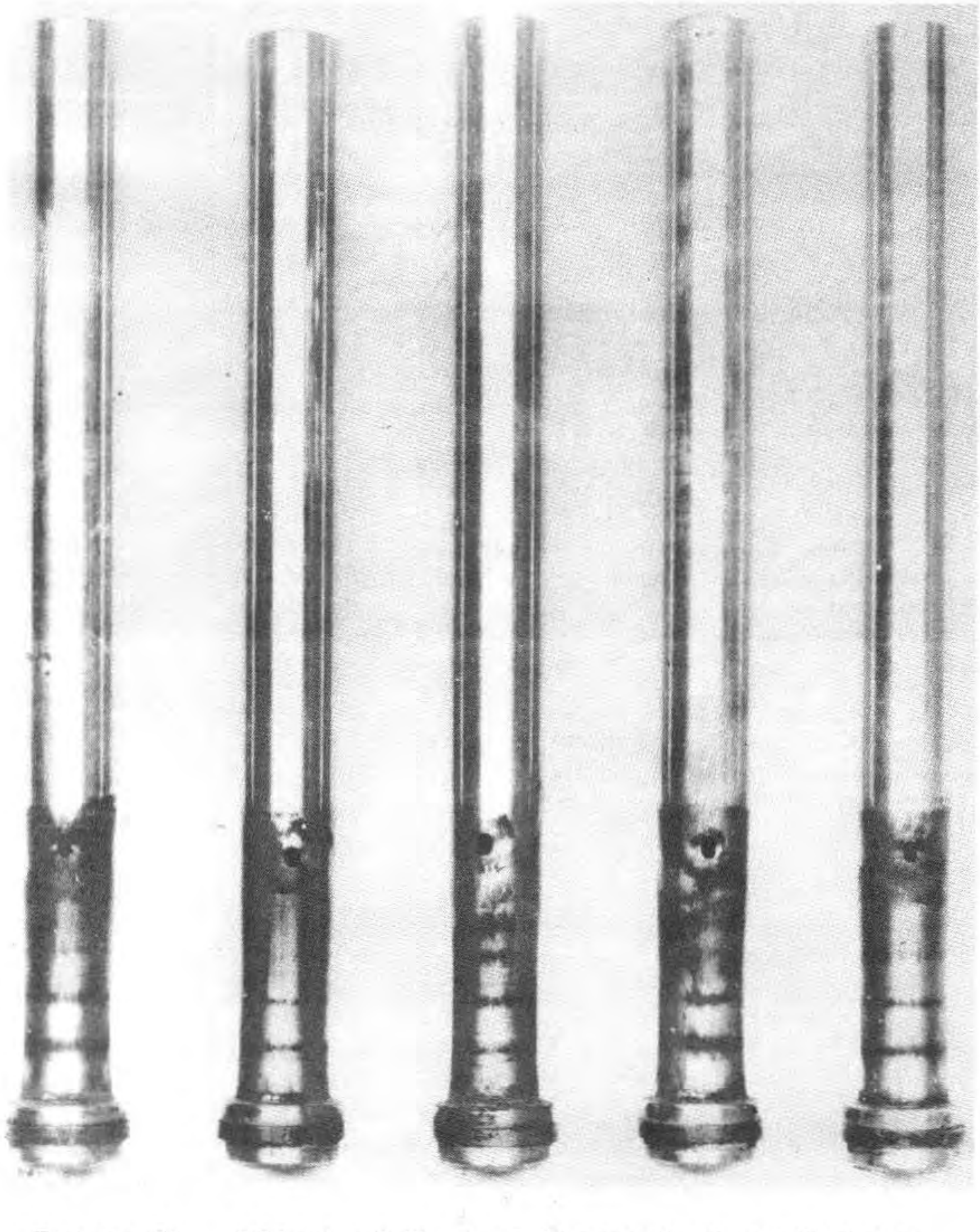


Figure 21. Effect of No-load Firing Test on Pistons

This value is well within the 10 to 20 fps velocity requirement spelled out in the specification. The total deviation over this range was 17.0 to 13.7 fps or 3.3 fps.

Structural Analysis

Although the XM14 thruster satisfied all design requirements, an analysis confirming the soundness of design was desirable. Stress figures for the body and piston in the normal firing, locked-shut, and no-load conditions were especially important. Also, an indication of the adequacy of the design in several other areas was desirable. The structural analysis of the thruster is presented in Appendix C.

CONCLUSIONS

The numerous firings conducted throughout the development and engineering evaluation programs definitely established the feasibility of this device. The XM14 thruster provides an average projectile chambering velocity of 15.65 ± 1.65 fps over the entire temperature range of $-30°$ to $+160°F$. This velocity is well within the 10 to 20 fps velocity specified, which is not attainable through hand ramming. It is sufficient to move a 95-pound projectile a distance of 61 inches to chamber the projectile in the 155 mm howitzer when the tray angle is $6°$ and the tank elevation is $0°$.

The new loading tray provides rapid positioning of the projectile during the firing cycle. When not in use, the tray can be folded to give the crew greater freedom of movement within the tank.

RECOMMENDATIONS

The Thruster, Cartridge Actuated, XM14, is small, rugged, and easily maintained, as compared with the rammer mechanism in present use. Utilizing an inexpensive standard cartridge (Cartridge, Rifle Grenade, Cal. 30, M3) as a gas generator, the problem of cartridge supply is minimized.

Since the feasibility of this device has been proved, exhaustive user tests are recommended. This should be followed by a program of final development and standardization to qualify the XM14 thruster for field use.

APPENDIX A

SPECIFICATION FOR PROJECTILE RAMMER FOR 155 mm HOWITZER WEAPON

Frankford Arsenal
RAD Group
18 March 1959

A. GENERAL

This specification covers the requirements for the design and development of a Projectile Rammer for the Self-Propelled, 155 mm Howitzer, T196. Drawing K-DTA-58710, Installation, Rammer Tray, dated 11 September 1958, and sub-assemblies listed thereon shall become a part of this specification, to be used as a guide to establish design limitations for the device.

B. RESPONSIBILITIES

1. Frankford Arsenal, within the scope of Phase I funding, shall design and develop this Projectile Rammer in accordance with the requirements of this specification.

Upon completion of the design stage, one complete prototype Projectile Rammer shall be fabricated, and one loading tray shall be modified to accept this Rammer. Approximately 22 firings shall be conducted as outlined below, to establish the charge.

Temp	Min. No. of Firings
-30°F	6
+70°F	10
+160°F	6

2. Frankford Arsenal, within the scope of Phase II funding, shall conduct Engineering Evaluation Tests on this device. A minimum of seventy-five (75) tests shall be conducted on the Projectile Rammer as outlined below, to assure compliance with the ballistic requirements.

Type of Test	Temp of Cartridge	Minimum Number of Tests
Average Performance	-30°F	20
	+70°F	20
	+160°F	20
No-Load	+160°F	5
Locked-Shut	+160°F	10

Upon completion of the Engineering Evaluation Tests, five (5) complete Projectile Rammer assemblies shall be fabricated for service mounting and forwarded to Detroit Tank Arsenal.

3. Frankford Arsenal will adhere to the time development schedule which is a part of this specification, and shall consult with the Detroit Tank Arsenal Vehicle Coordinator periodically, for guidance and performance approval.

4. Frankford Arsenal will furnish monthly progress reports (as specified in Paragraph 4, PESD dated 28 April 1958) through completion of program.

5. Upon completion of engineering tests, Frankford Arsenal shall furnish one complete set of Ordnance drawings (vellums) to cover this device.

6. Three (3) copies of a final report, complete with charts, graphs, calculations, data, performance curves, etc., shall be prepared by Frankford Arsenal, and forwarded to Detroit Tank Arsenal within a period of forty-five (45) days after completion of the Engineering Evaluation Tests.

C. REQUIREMENTS

1. This specification proposes the use of a simple, fast loading, propellant cartridge powered device, electrically or mechanically initiated, to drive the projectile from the loading tray into the gun chamber. It may be mounted in one of three positions:

(a) On tray, for direct action against base of projectile.

(b) Underslung to tray directly under projectile location, with action against base of projectile.

(c) Underslung to tray, immediately forward of present quick disconnect (in location of present pneumatic rammer).

C. 1. (a) above is the most desirable location, and C. 1. (c) the least desirable. Its location at C. 1. (c) would limit operational accessibility to five inches.

2. The device shall comprise a fast loading hot gas generator and a rammer cylinder. The gas generator and cylinder shall be designed for a 500 to 1000 cycle life. Both components shall withstand a minimum Tank sortie of 25 rounds before requiring any maintenance. Minimum maintenance will be permitted after this 25-round firing cycle.

3. Provision must be made near the end of piston stroke to uncover a port or valve to reduce the pressure within the cylinder, so that the internal pressure will be close to atmospheric when the firing mechanism is opened to eject the cartridge case, and to permit repositioning of piston for the next firing.

4. The Rammer device shall be so designed to allow recharging operation at a rate of 3 to 4 rounds per minute. The Rammer shall be designed to impart a uniform velocity. This velocity measured at the end of power stroke shall not exceed 20 feet per second to permit easy push-out (from the muzzle end) in the event the firing is cancelled, and shall not be less than 10 feet per second to assure positive chambering.

5. Additional information pertinent to the design of the device is outlined below:

(a) Weight of projectile; 95 pounds

(b) Additional moving parts currently in the system (to be accelerated to chamber the projectile); 22.4 pounds

(c) Projectile travel from static tray position to chamber; 61 in.

(d) Power stroke; 11 inches maximum

(e) Deviation of projectile velocity at end of power stroke, (over entire temperature range); ± 2 feet/second (15.8 feet per second, mean desired projectile velocity)

(f) Tray elevation; 6 degrees (at zero degrees Tank elevation)

(g) Presently existing Rammer arm strength may be increased by gusset reinforcement. The weight of this reinforcement shall be added to (C. 5. b) above.

(h) Weight of this device shall be kept to the minimum consistent with its rugged duty requirements.

(i) Device must withstand both the no-load and locked-shut firing conditions at +160°F, without damage that would require repair to further use.

D. Upon completion of contractual effort all serviceable hardware, miscellaneous components, cartridges, etc, surplus to this program, shall be properly inventoried and returned to Detroit Tank Arsenal.

APPENDIX B

CONVERSION OF VELOCITY OF TEST MASS TO CHAMBERING VELOCITY

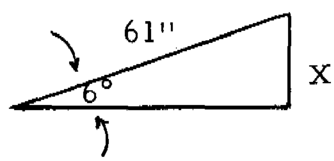
The velocity of the test mass can be converted to a chambering velocity by a relatively simple calculation. First, find the total energy present. Subtract from this figure the energy lost during the shell's 61-inch travel up the tray at an angle of 6° above the horizontal. It should be remembered that, because the test mass travels 3 inches vertically before the velocity is read, the additional height that the shell advances on the tray is all that must be accounted for.

<u>Sample Calculation</u>

1. Conversion of a typical value is shown as follows:

(a) $KE_{Tot_{av}} = 1/2\ MV^2 = 1/2 \times \frac{95}{32} \times 16.7^2 = 413$ ft-lb

(b) Height shell must overcome



$$X = \frac{61}{12} \text{ Sin } 6°$$

$$X = 0.1045 \times 5.08 = 0.532 \text{ ft}$$

Because the test mass has already traveled 3 inches or 0.250 foot, the total increased loss will be:

Loss due to PE = Wh = 95 x (0.532 - 0.250) = 26.8 ft-lb

(c) Loss due to friction:

$$KE_{loss\ friction} = \frac{61}{12} \times 95 \times .1 = .508 \times 95 = 48.3 \text{ ft-lb}$$

(d) Therefore, the correct velocity must be:

$$KE = 1/2\ MV^2$$

$$\sqrt{\frac{2\ KE}{M}} = V = \sqrt{\frac{2\ (413 - (26.8 + 48.3))}{\frac{95}{32}}}$$

$$= \sqrt{\frac{2\ (337.9)}{2.97}} = \sqrt{\frac{675.8}{2.97}} = \sqrt{228}$$

$$= 15.1 \text{ fps}$$

Values shown in Tables XIII and XX were converted in this manner.

APPENDIX C

STRUCTURAL ANALYSIS

The following analyses were made:

a. Piston

(1) Locked-shut

(2) Normal firing

(3) No-load

b. Body

(1) Locked-shut

(2) Normal firing

(3) No-load

c. Weld strength, bracket-to-tube

(1) Locked-shut

d. Tubes

(1) Locked-shut

e. Pins

(1) Locked-shut

Due to their great relative size, the mounting fixture and the adapter were not analyzed structurally.

Piston

The object of the analysis was to determine the stresses on the piston due to direct compression on firing in the locked-shut condition, adequacy of the piston relative to column failure in this condition, and the tensile stresses in the piston at impact with the body (figure 22) in a no-load firing. Data available from testing included pressure-time curves for all three firing conditions, and velocity measurements for the piston in normal and no-load firings. Compressive force due to gas pressure = PA_{net}, where A_{net} is the piston shank area at the large axial hole. Compressive stress is maximum at the radial hole, its magnitude being

$$S_c = \frac{PA_{net}}{A_{net} - D_h (D_o - D_i)}$$

where D_h = radial hole diameter.

$P = 15,500$ psi, and $A_{net} = 0.229$ in.^{2}, so

$$S_c = \frac{15500 \times 0.229}{0.229 - 0.028} = 17,650 \text{ psi.}$$

The piston was fabricated of type 303 stainless steel having a yield point of 30,000 psi and an ultimate strength of 80,000 psi.

$$\text{Factor of safety} = \frac{30,000}{17,650} = 1.7 \text{ (yield).}$$

For column failure, $P_{cr} = \dfrac{4\pi^2 EI}{\ell^2} = 3.92 \times 10^5$ lb, assuming both ends of the piston are built in and the cross section is constant at its smallest value. (In view of the piston configuration, it was felt that these assumptions were fairly realistic.) At any rate, the axial load was 3550 lb. so that column failure was not the limiting factor.

To find the tensile stress in the piston at impact with the cylinder in a no-load shot, another item of test data was employed - the fact that a no-load firing imposed a permanent extension, accompanied by lateral contraction, on about 2.5 inches of the 6.5 inch length. We assume that the stress in the piston is a function of its length (refer to figure 22), specifically, proportional to the distance from the forward end. Under

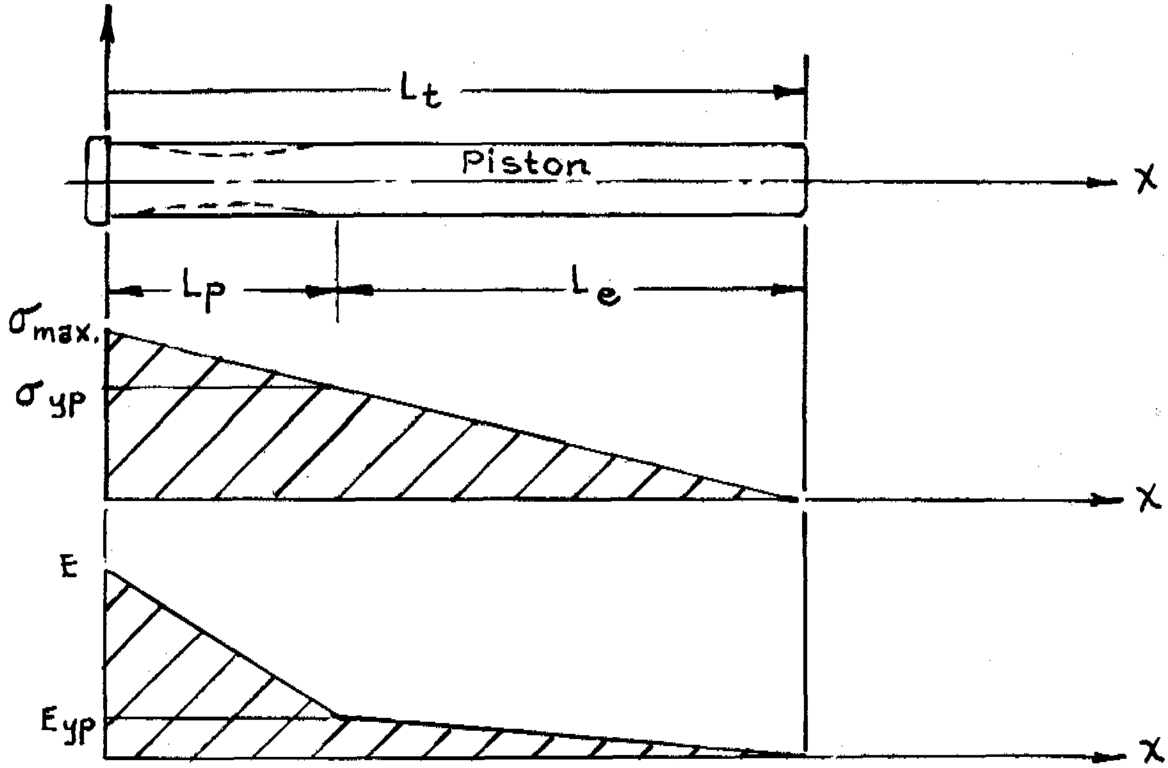


Figure 22. Longitudinal Stress Diagram

this assumption, we find that $\sigma = \sigma(x)$; $\sigma = CX$, where C is a constant. Letting L_p and L_t indicate the final piston length in plastic deformation and its total length, respectively, we have,

$$L_p = XL_t \text{ (X a constant, } < 1\text{), or } X = \frac{L_p}{L_t} = \frac{2.5}{6.5} = 0.385 \text{ inch.}$$

Also, $\sigma_{max} = \sigma_{yp} (1 + \frac{L_p}{L_e})$, where L_e = elastic length;

$$\sigma_{max} = \sigma_{yp} (1 + \frac{L_p}{L_t - L_p}) = \sigma_{yp} (1 + \frac{XL_t}{L_t - XL_t});$$

$\sigma_{max} = \sigma_{yp} (\frac{1}{1 - X})$, and, since X = 0.385 inch,

$$\sigma_{max} = \frac{30000}{0.615} = 48,700 \text{ psi.}$$

The factor of safety = $\frac{80000}{48700}$ = 1.64 (ultimate).

Here, we have used σ_{yp} = 30,000 psi, a figure taken from static stress-strain data and of doubtful accuracy for the conditions of this problem. For lack of curves of stress and strain vs rate of loading, however, this figure must be used.

Body

For the body, the most severe stresses would occur under the maximum pressures developed in a locked-shut firing. There are no shear stresses on the cylinder, so that the three coordinate stresses calculated are principal stresses, the largest being the hoop stress (tension). By the formula

$$(\sigma_T)_{max} = P_i \frac{r_o^2 + r_i^2}{r_o^2 - r_i^2}$$

we find that $(\sigma_T)_{max}$ at the inner surface equals 49,600 psi.

Of course, $(\sigma_R)_{max}$, the radial compressive stress, was equal to P_{max} = 15,500 psi, while the axial stress, calculated from P/A, was about 2500 psi in tension. The $(\sigma_T)_{max}$ value above was for the section at the external flats, calculated on the basis of an outer diameter equal to the distance between the flat surfaces.

The body is made of 17-4HP stainless steel having a yield strength of 110,000 psi and an ultimate strength of 150,000 psi.

Factor of safety = $\frac{110000}{49600}$ = 2.22 (yield).

The longitudinal stress on the body in a no-load shot would be less than that on the piston since the body area is greater. The piston has not failed and the yield strength of the cylinder material is considerably above the ultimate of the piston. The body, therefore, is in no danger of gross yielding.

Weld Strength, Bracket to Tube

If the entire length of these welds (Figure 23) is assumed to be effective, we have a total normal stress of 3700 psi, calculated from the formula $S_h = 1.618 \frac{F}{Lh}$, where F is applied force, L is weld length,

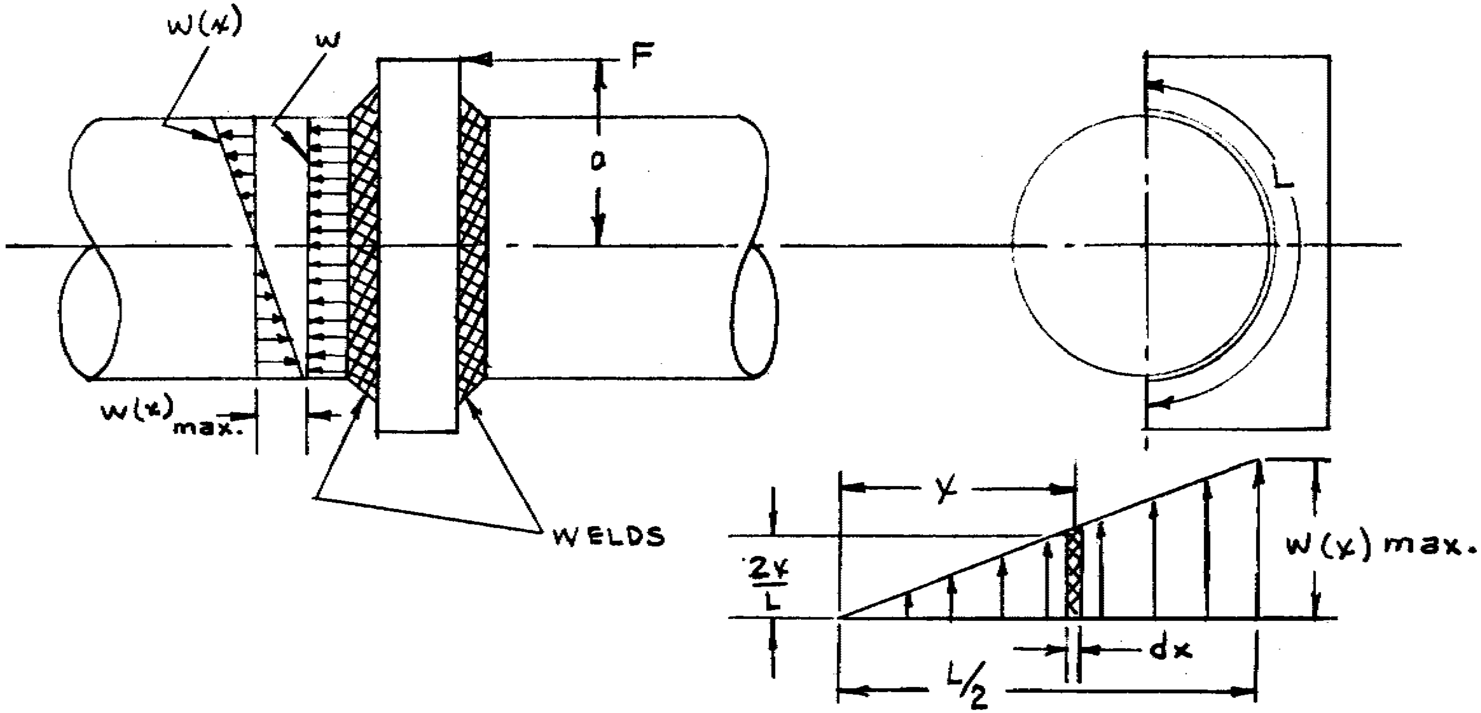


Figure 23. Forces Exerted on Weld Joints

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